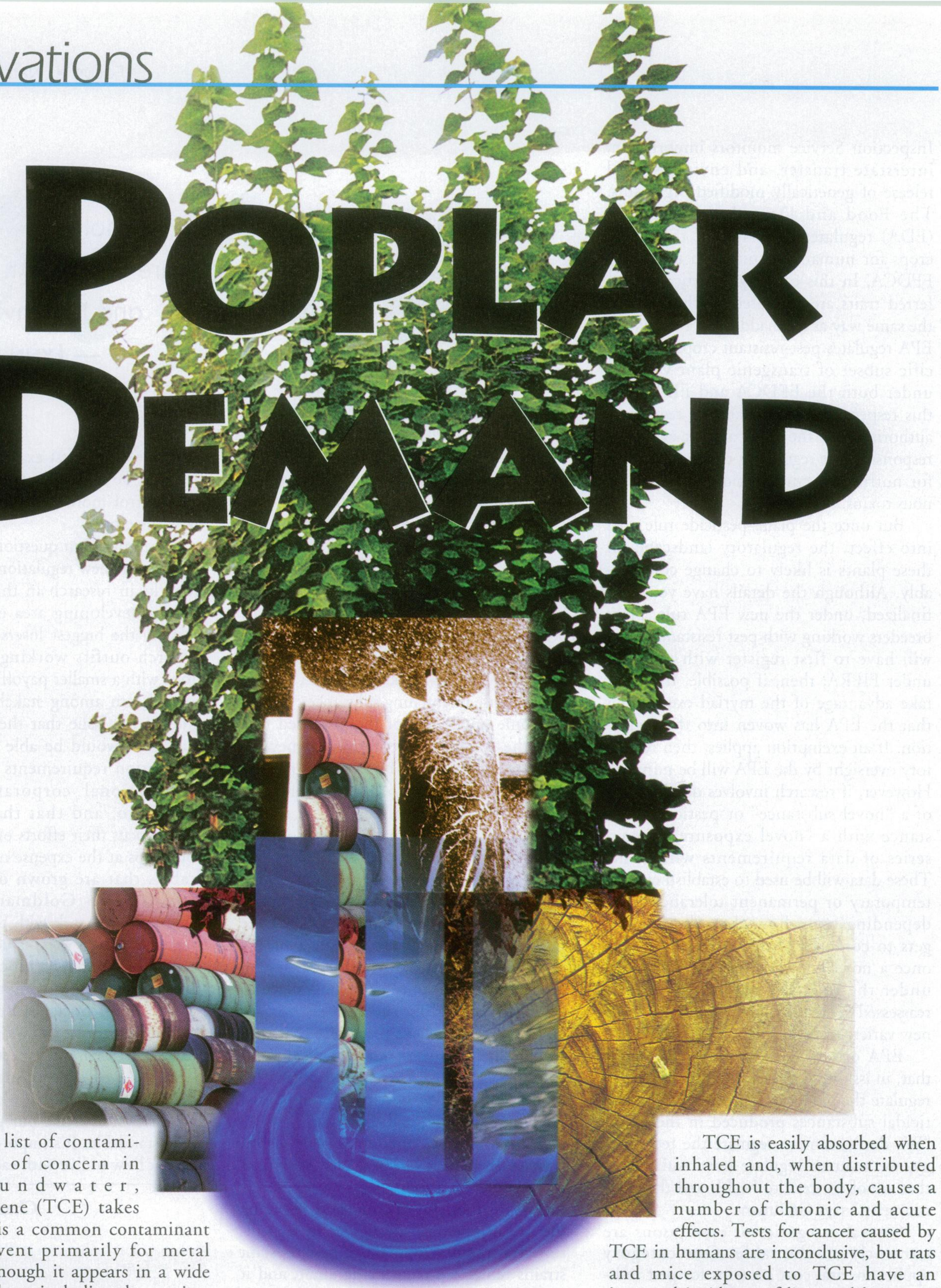
Poplar Demand



Poplar tree photo credit: Milton Gordon

On the list of contaminants of concern in groundwater, trichloroethylene (TCE) takes first place. It is a common contaminant used as a solvent primarily for metal degreasing, although it appears in a wide variety of products including dyes, printing inks, and spot removers, and in the manufacture of polyvinyl chloride, adhesives, and paints. It is also a common inert ingredient in fungicides and insecticides.

TCE poses a particular problem in groundwater because it can take months or years to degrade, unlike in surface water, where it disappears into the atmosphere within a few weeks. When TCE is broken down by microbes in the soil surrounding the groundwater, it results in the formation of vinylidene chloride, a suspected human carcinogen, and vinyl chloride, a known human carcinogen. Approximately 38% of cities that rely on groundwater for municipal supplies show average TCE contamination levels above the EPA drinking water quality criteria. Contamination is frequently found in wells close to refineries, metal processing plants, chemical manufacturers, military bases, and electroplating operations.

TCE is easily absorbed when inhaled and, when distributed throughout the body, causes a number of chronic and acute effects. Tests for cancer caused by TCE in humans are inconclusive, but rats and mice exposed to TCE have an increased incidence of liver and lung cancers. Although TCE was once thought safe enough to serve as a dry-cleaning solvent, fumigant, and general anesthetic, it is now considered a probable human carcinogen.

The principle methods for remediating TCE-contaminated groundwater are slow and expensive, and include pumping water from the aquifer and stripping the TCE from it by aeration or charcoal absorption. Bacteria have been used in TCE decontamination, but this approach requires inducers such as toluene and phenol—which may present their own human health hazards—for degradation to occur.

Poplar Remediation

Phytoremediation, the use of green plants for environmental remediation, offers an alternative approach to TCE cleanup that may be substantially less expensive, is more straightforward, requires less maintenance, and is aesthetically more appealing to the public than traditional methods. This approach has gained credibility in the 15 years since it first emerged as an area of research interest. Numerous projects are underway to test different flora for the ability to absorb or break down the full range of organic and inorganic toxic compounds of concern in the environment. Several small companies have been formed by researchers to pursue commercial applications of phytoremediation techniques, with large environmental engineering firms also beginning to incorporate phytoremediation into their services.

Rufus Chaney, a senior research agronomist at the U.S. Department of Agriculture in Beltsville, Maryland, and one of the founders of the phytoremediation field, says, "Trees have a great advantage over microbes [for decontamination] because a plant pumps energy down to its roots and therefore has more [of that energy] available to break down pollutants. Microbes in the soil need to be able to feed on the pollutant itself to get energy." Chaney emphasizes that plants can provide two vital functions in remediation: both the capture and the biodegradation of pollutants.

Poplar trees have proven particularly effective at breaking down TCE and are the focus of research by Milton Gordon, a professor of biochemistry at the University of Washington in Seattle, and colleagues Lee Newman, Stuart Strand, and Paul Heilman, all forestry researchers from Washington State University in Puyallup. Fast-growing and thirsty, the poplar grows in regions from Central America to southern Alaska, and so has wide geographic applicability.

A hybrid poplar such as the one used by the Washington researchers can grow 3 m or more per year and, with its deep root structure, can pump large quantities of water out of the ground. A five-year-old tree transpires 100–200 l of water per day, depending on conditions. In addition to its ubiquity, the poplar was chosen because the University of Washington has a 20-year history of working with the physiology and cultivation of genetically engineered poplars.

The idea for using poplar trees came to Gordon 10 years ago while talking to his brother, then a researcher at Occidental Chemical Corporation in Grand Island, New York. As with many chemical companies, Occidental had generated TCE and other chlorinated materials, and was interested in finding innovative remediation technologies. "We started talking about the possibility of using bacteria, but then came up with the idea of poplars," says Gordon.

Gordon says his main focus is on trying to develop a means of cleaning up spills of chlorinated organics, noting, "People won't object to plants. This way is more socially acceptable, easier, and cheaper to use." The trees used in the experiments so far have been hybrids, but Gordon plans to genetically engineer future trees with genes that can handle other types of organic pollutants, and to find species potentially better suited to different climates or chemicals. Steve Strauss, a professor of forestry science at Oregon State University in Corvallis who breeds poplars for timber, observes the value in developing a TCE-removing tree that has other useful traits such as insect resistance and low management needs. "The important thing," he says, "is to first find the wild type that works best."

Gordon has enough faith in the future of phytoremediation to have formed his own company—Verdant Technologies—which he set up to perform routine remediation of organic contamination. Instead of being limited to research, his company hopes to be able to apply the technology to specific sites.

Potted Plants

The research team did much of their experimental work by growing rooted poplar cuttings in PVC pipes that were 20.5 cm in diameter and contained a 30-cm bottom layer of sand overlaid with 60 cm of soil. Over a period of 8 months, 8 g of TCE were slowly added to the plants' water. The researchers performed axenic cell culture tests (in which only one type of microorganism, the poplar cells themselves, are growing) on small root cuttings and used a bioreactor to determine the distribution of most of the TCE metabolized. All tests indicated that the trees could withstand levels of TCE exceeding those found at a typical remediation site, and that the transpiration of TCE was extremely low or undetectable. The researchers now are conducting a field trial to evaluate the performance of a poplar hybrid—the clone *Populus trichocarpa* x *Populus deltoides*, known as H11-11.

It seems that the TCE is oxidized as it moves from the bottom roots to the upper sections of the crown of the plant. As a result, the researchers have come to believe that the tree fully metabolizes TCE. Soil microorganisms also degraded some TCE, but axenic experiments showed conclusively that the poplar cells are capable of transforming and mineralizing TCE with oxidative enzymes and do not require the microorganisms.

The field trial now underway involves an artificial aquifer into which double-walled cells of heavy-gauge plastic sheeting measuring 3.7 m x 6.1 m x 1.5 m were inserted. Four cells were planted with 30-cm hybrid poplars. Through a piping system, two of these cells were dosed with water containing 50 parts per million TCE, while the other two received untreated water. So far, this field trial has confirmed the results of the lab experiments and 95% of the added TCE has been removed. "We're not seeing TCE in the leaves or twigs," says Gordon. "There seems to be no bioaccumulation or evaporation of TCE." He and his colleagues believe that the trees completely degrade TCE to chloride salts. TCE metabolites may be incorporated into insoluble plant materials such as lignin.

The field trial is taking place on previously remediated property owned by Occidental near Fife, Washington. Occidental's project manager, James Duffy, says the poplars are attractive for limited uses if the contamination is not too deep. "It's not fast, but it offers cost advantages over the historical method of digging up the dirt and burning it," he says.

Onward, with Questions

The question of toxic metabolites in the plant tissue is an important one to Jerald Schnoor, a professor of civil and environmental engineering at the University of Iowa in Iowa City, who has been conducting similar research on poplars for over 10 years. "We must make sure that the TCE is not bioavailable," he says. "We want phytoremediation to result in both ecological and human risk reduction, and to get risk reduction we have to understand pathways."

Schnoor adds that there are not a lot of full-scale field data on the technology yet. "It costs less," he says, "but real hard proof of efficacy remains to be seen. Certainly within the next few years we should have the evidence." Schnoor thinks it's very important that the test sites be chosen carefully. With the technology so young, a few cases where efficacy is not proven could damage the method's credibility.

Paul Thomas, a consultant on site remediation with Thomas Consulting in Cincinnati, Ohio, is another cautious fan of phytoremediation. Thomas believes that TCE is one of the most likely contaminants to be readily attenuated by the technology. "Some people are concerned that the technology is way ahead of the science. There are lots of other mechanisms at work in the soil that no one understands. So we are years away from saying 'this is how plants take up organic chemicals and make them go away.'"

Phytoremediation technologies act to speed up the natural attenuation process, and so have popular appeal. But, echoing Schnoor's concern, Thomas says phytoremediation will work only under specific circumstances, and not many people are qualified to determine when it is appropriate. With industry and the military funding much of the research, the public could become disenchanted if phytoremediation is seen simply as a tool to defy regulators and more aggressive cleanup actions.

Among the best things about the work of Gordon's team is that it brings together the disciplines of plant biology, remediation, molecular biology, physiology, and ecology, says William Suk, director of the Office of Program Development of the NIEHS Division of Extramural Research and Training, which sponsors the poplar research through the Superfund Basic Research Program. The cross-disciplinary nature of the work allows researchers to investigate and integrate all aspects of remediation.

"If poplar remediation is done in tandem with other technologies, I don't see why it can't be applied to other chemicals and other field situations," says Suk. In the bigger picture, phytoremediation represents an important partnership between the federal government, industry, and the research community. But most important, he adds, "It's a long-term research investment that is beginning to bear fruit."

W. Conard Holton

Suggested Reading

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